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NOTICE

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1 Navy Case No. 78001

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3 HYBRID NEURAL NETWORK FOR PATTERN RECOGNITION

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5 STATEMENT OF GOVERNMENT INTEREST

6 The invention described herein may be manufactured and used  
7 by or for the Government of the United States of America for  
8 governmental purposes without the payment of any royalties  
9 thereon or therefor.

10  
11 CROSS REFERENCE TO RELATED PATENT APPLICATION

12 The present invention is related to co-pending U.S. Patent  
13 Application entitled WAVELET-BASED HYBRID NEUROSYSYTEM FOR SIGNAL  
14 CLASSIFICATION, By Chung T. Nguyen et al. (Navy Case No. 78080)  
15 having the same filing date.

16  
17 BACKGROUND OF THE INVENTION

18 (1) Field of the Invention

19 The present invention relates to a system and a method for  
20 recognizing patterns which has particularly utility in the field  
21 of combat system technology and to the area of signal processing,  
22 feature extraction and classification.

23 (2) Description of Prior Art

24 In a conventional pattern recognition system, the task to be  
25 performed is divided into three phases: data acquisition; data  
26 preprocessing; and decision classification. FIG. 1 is a

1 schematic representation of a conventional pattern recognition  
2 system. In the data acquisition phase 10, analog data from the  
3 physical world are gathered through a transducer and converted to  
4 digital format suitable for computer processing. More  
5 particularly, the physical variables are converted into a set of  
6 measured data, indicated in FIG. 1 by electric signals,  $x(r)$ , if  
7 the physical variables are sound (or light intensity) and the  
8 transducer is a microphone (or photocells). The measured data is  
9 then used as the input to the second phase 12 (data  
10 preprocessing) and is grouped in a third phase 14 into a set of  
11 characteristic features,  $P(i)$ , as output. The third phase 14 is  
12 actually a classifier or pattern recognizer which is in the form  
13 of a set of decision functions.

14 Signal classification or pattern recognition methods are  
15 often classified as either parametric or nonparametric. For some  
16 classification tasks, pattern categories are known a priori to be  
17 characterized by a set of parameters. A parametric approach is  
18 to define the discriminant function by a class of probability  
19 densities by a relatively small number of parameters. There  
20 exist many other classifications in which no assumptions can be  
21 made about the characterizing parameters. Nonparametric  
22 approaches are designed for those tasks. Although some  
23 parameterized discriminant functions, e.g. the coefficients of a  
24 multivariate polynomial of some degree, are used in nonparametric  
25 methods, no conventional form of the distribution is assumed.

1           In recent years, one of the nonparametric approaches for  
2 pattern classification is neural network training. In neural  
3 network training for pattern classification, there are a fixed  
4 number of categories (classes) into which stimuli (activation)  
5 are to be classified. To resolve it, the neural network first  
6 undergoes a training session, during which the network is  
7 repeatedly presented a set of input patterns along with the  
8 category to which each particular pattern belongs. Then later  
9 on, there is presented to the network a new pattern which has not  
10 been presented to it before but which belongs to the same  
11 population of patterns used to train the network. The task for  
12 the neural network is to classify this new pattern correctly.  
13 Pattern classification as described here is a supervised learning  
14 problem. The advantage of using a neural network to perform  
15 pattern classification is that it can construct nonlinear  
16 decision boundaries between the different classes in  
17 nonparametric fashion, and thereby offer a practical method for  
18 solving highly complex pattern classification problems.

19           Signal classification involves the extraction and partition  
20 of feature of targets of interest. In many situations, the  
21 problem is complicated by the uncertainty of the signal origin,  
22 fluctuations in the presence of noise, the degree of correlation  
23 of multi-sensor data, and the interference of the nonlinearities  
24 in the environment. Research and studies in the past have  
25 focused on developing robust and efficient methods and devices  
26 for recognizing patterns in signals, many of which have been

1 developed from traditional signal processing techniques, and  
2 known artificial neural network technology. There still remains  
3 however a need for a system and a method for providing high  
4 classification performance.

#### 5 6 SUMMARY OF THE INVENTION

7 Accordingly, it is an object of the present invention to  
8 provide a system and a method which enables high classification  
9 performance.

10 It is a further object of the present invention to provide a  
11 system and a method as above which has and utilizes a self-  
12 organizing feature architecture.

13 The foregoing objects are attained by the system and the  
14 method of the present invention.

15 In accordance with the present invention, a system for  
16 recognizing patterns comprises first means for extracting  
17 features from inputted patterns and for providing topological  
18 representations of the characteristics of the inputted patterns  
19 and second means for classifying and recognizing the inputted  
20 patterns. In a preferred embodiment of the present invention,  
21 the first means comprises two one-layer neural networks and the  
22 second means comprises a feedforward two-layer neural network.

23 Further in accordance with the present invention, a method  
24 for recognizing patterns broadly comprises the steps of providing  
25 first and second neural networks each having an input layer  
26 formed by a plurality of input neurons and an output layer formed

1 by a plurality of output neurons, supplying signals  
2 representative of a set of input patterns to the input layers of  
3 the first and second neural networks, training the first and  
4 second neural networks using a competitive learning algorithm,  
5 and generating topological representations of the input patterns  
6 using the first and second neural network means. The method  
7 further comprises providing a third neural network means for  
8 classifying and recognizing the input patterns and training the  
9 third neural network means with a back-propagation algorithm so  
10 that said third neural network means recognizes at least one  
11 interested pattern.

12 Other details of the system and the method of the present  
13 invention, as well as other objects and advantages attendant  
14 thereto, are set forth in the following detailed description  
15 wherein like reference numerals depict like elements.

16  
17 BRIEF DESCRIPTION OF THE DRAWINGS

18 FIG. 1 is a schematic representation of a prior art pattern  
19 recognition system;

20 FIG. 2 is a schematic representation of a layout of a hybrid  
21 neural network for pattern recognition;

22 FIG. 3 is a schematic representation of the architecture of  
23 the feature extraction neural network used in the neural network  
24 of FIG. 2; and

1           FIG. 4 is a schematic representation of the architecture of  
2 the classification neural network used in the neural network of  
3 FIG. 2.

#### 4 5           DESCRIPTION OF THE PREFERRED EMBODIMENT

6           As previously discussed, the present invention relates to a  
7 system and to a method for pattern recognition which utilize  
8 advanced neural network training algorithms to train a hybrid  
9 neural network. The term "hybrid" in the foregoing context  
10 refers to the fact that the architecture includes components  
11 utilizing different types of network training algorithms with the  
12 different algorithms contributing to the performance of a single  
13 function. Information presented to the system is in the form of  
14 characteristic features of the underlying signal. Based on the  
15 distinction in the signal's characteristics, the system  
16 classifies and associates each input data to its corresponding  
17 category.

18           Referring now to the drawings, FIG. 2 illustrates the layout  
19 of the hybrid neural network system 20 for pattern recognition of  
20 the present invention. As shown therein, the hybrid neural  
21 network system 20 consists of three separate artificial neural  
22 networks 22, 24, and 26 and is divided into two stages 28 and 30.

23           The first stage 28 is known as the feature extraction stage  
24 and consists of two neural networks 22 and 24. The networks 22  
25 and 24 are each one-layer networks with lateral connections among  
26 output neurons. The networks 22 and 24 are each trained with an

1       unsupervised learning algorithm. The second stage 30 of the  
2       system is the signal classification network. This stage is  
3       formed by a fully connected, feedforward two-layer network 26  
4       which is trained with a back-propagation algorithm.

5       Referring now to FIG. 3, each of the neural networks 22 and  
6       24 used for feature extraction consists of an input layer 32  
7       formed by a plurality of input layer neurons 38 and an output  
8       layer 34 formed by a plurality of output layer neurons 40 with  
9       synaptic feedforward (excitatory) connections 36 from the input  
10      layer neurons 38 to the output layer neurons 40 and lateral  
11      (inhibitory) connections 42 among neurons 40 in the output layer  
12      34. The output neurons generate outputs  $Y_1$  through  $Y_j$ , where  $j$   
13      equals the number of output neurons. In each network, the neuron  
14      cells at the output layer compete in their activities by means of  
15      mutual lateral interactions and develop adaptively into specific  
16      detectors of different signal patterns through an unsupervised  
17      learning process. In one embodiment of the present invention,  
18      each network 22 and 24 may consist of 100 neurons (50 input  
19      neurons and 50 output neurons) with each output neuron 40 being  
20      fully connected to the 50 input neurons 38.

21      The input neurons 38 in the input layer 32 of each network  
22      receive input signals  $x_1 - x_i$ , where  $i$  equals the number of input  
23      neurons 38, in digital form, which input signals contain  
24      information about certain properties or characteristics of the  
25      underlying signals from a data acquisition source. While the two  
26      neural networks 22 and 24 forming the feature extraction stage 28



1 are identical in architecture, they receive different input  
2 information.

3 Each of the networks 22 and 24 is designed so that at a  
4 given time only one neuron cell or a local group of neuron cells  
5 gives an active response to the current input. As a result, the  
6 locations of the responses tend to become ordered as if  
7 meaningful coordinate systems for different input features were  
8 being created over the network. The spatial location of a cell  
9 in the network corresponding to a particular domain of signal  
10 patterns provides an interpretation of the input information.

11 A set of competitive learning rules based on the Kohonen  
12 algorithm may be used to train each of the neural networks 22 and  
13 24 forming the feature extraction stage 28. As unsupervised  
14 training progresses using these competitive learning rules, a  
15 feature map evolves which provides a topological representation  
16 of the input patterns.

17 Each feature extraction network 22 and 24 generates a  
18 topological map as follows. At the input layer 32 of the feature  
19 extraction neural network 22 or 24, properties or characteristics  
20 of the input information, i.e. times, amplitude, phase, wavelet  
21 transform location output information, wavelet transform  
22 magnitude information, etc., are inputted. Illustrative of an  
23 embodiment of system 20 which is of special utility in connection  
24 with an application of underwater acoustics to classify sounds  
25 emitted by torpedoes is the system described in the above  
26 identified co-pending application filed on an even date herewith

1 of C.T. Nguyen, S.E. Hammel and K.F. Gong entitled "Wavelet-Based  
2 Hybrid Neurosystem for Signal Classification" (Navy Case No.  
3 78080), hereby incorporated by reference herein. When processing  
4 this information, each input neuron 38 computes the data it  
5 receives and presents the result to each of the neurons 40 of the  
6 output layer 34. There, the lateral connections 42 perform  
7 lateral inhibition, with each neuron 40 tending to inhibit the  
8 neuron 40 to which it is laterally connected. The final  
9 processing results, sometimes referred to as a topological map,  
10 are forwarded to stage 30 for operation with or for the training  
11 of the classification network 26.

12 As previously discussed, a competitive learning algorithm is  
13 used to train the feature extraction networks 22 and 24. In  
14 competitive learning, the output neurons of a neural network  
15 compete among themselves to be the one to be active. Thus, only  
16 a single output neuron is active at any one time. It is this  
17 feature that makes competitive learning highly suited to discover  
18 those statistically salient features that may be used to classify  
19 a set of input patterns. There are three basic elements to a  
20 competitive learning rule. They are: (1) a set of neurons that  
21 are all the same except for some randomly distributed synaptic  
22 weights, and which therefore respond differently to a given set  
23 of input patterns; (2) a limit imposed on the "strength" of each  
24 neuron; and (3) a mechanism that permits the neurons to compete  
25 for the right to respond to a given set of inputs, such that only  
26 one output neuron is active at a time. Accordingly, the

1 individual neurons of the network learn to specialize on sets of  
2 similar patterns, and thereby become a feature detector or  
3 feature extractor.

4 The competitive learning algorithm used in the method of the  
5 present invention to train each network 22 and 24 is as follows.  
6 For output neuron  $j$  to be the winning neuron, its net internal  
7 activity level,  $v_j$ , for a specified input pattern  $x$  must be the  
8 largest among all the neurons in the network. The output signal,  
9  $y_j$ , of the winning neuron  $j$  is set equal 1; the output signals of  
10 all the neurons that lose the competition are set equal to zero.

11 Let  $w_{ji}$  denote the synaptic weight connecting input node  $i$  to  
12 neuron  $j$ . Each neuron is allotted a fixed amount of synaptic  
13 weight (all synaptic weights are positive), which is distributed  
14 among its input nodes; that is

$$\sum_i w_{ji} = 1, \quad \forall j \quad (1)$$

15 A neuron learns by shifting synaptic weights from its inactive to  
16 active input nodes. If a neuron does not respond to a particular  
17 input pattern, no learning takes place in that neuron. If a  
18 particular neuron wins the competition, then each input node of  
19 that neuron relinquishes some proportion of the synaptic weight,  
20 and the weight relinquished is then distributed equally among the  
21 active input nodes. In a standard competitive learning rule, the  
22 change  $\Delta w_{ji}$  applied to synaptic weight  $w_{ji}$  is defined by:

$$\Delta w_{ji} = \begin{cases} \eta (x_i - w_{ji}) & \text{if neuron } j \text{ wins} \\ 0 & \text{if neuron } j \text{ loses} \end{cases} \quad (2)$$

where  $\eta$  is the learning rate parameter. This rule has the overall effect of moving the synaptic weight vector  $w_j$  of winning neuron  $j$  toward the input pattern  $x$ . To this end, each of the output neurons has discovered a set of feature of inputs.

The classification artificial neural network 26 is preferably a standard two-layer, fully connected feedforward network. The architecture of this network may be termed a multilayer perceptron configuration. The classification neural network 26 is trained in a supervised manner to recognize one particular type of the interested patterns using an algorithm known as the error back propagation algorithm or back propagation algorithm. This algorithm is based on the error correction learning rule:

$$\Delta w_{ji}(n) = -\eta \frac{\partial \epsilon(n)}{\partial w_{ji}(n)} \quad (3)$$

where  $\eta$  is a constant that determines the rate of learning,  $\Delta w_{ji}$  is the correction weight, and  $\epsilon$  is the error. The use of the minus sign in Equation (3) accounts for the gradient descent in weight space.

The architecture of the classification neural network 26 is shown in FIG. 4. As shown therein, there are three layers in its configuration: an input layer 44 formed by a plurality of input

1       neurons 50, a hidden layer 46 formed by a plurality of neurons  
2       52, and an output layer 48 formed by one output neuron 54. The  
3       input layer 44 is preferably constructed with 100 input neurons  
4       with each input neuron receiving information from a respective  
5       output neuron 40 in the feature extraction networks 22 and 24.  
6       The hidden layer 46 consists of 20 neurons. At the end of the  
7       training, the classification neural network 26 performs a binary  
8       classification on each given input pattern. The outputs of the  
9       classification network 26 are designated as "1" and "0" for  
10      matched signal or no-match signal, respectively.

11       As can be seen from the foregoing description, a novel  
12      hybrid neural network for pattern recognition has been presented.  
13      The concept of a hybrid neural network architecture in accordance  
14      with the present invention which incorporates different training  
15      algorithms makes the system unique and provides high  
16      classification performance. More particularly, the hybrid neural  
17      network providing the intermediate result of a self-organizing  
18      feature map in accordance with the present invention offers the  
19      following advantages.

20       The self-organizing system architecture discussed  
21      hereinbefore has been designed as a viable alternative to more  
22      traditional neural network architectures. The feature extraction  
23      components in the system function as self-organizing systems to  
24      provide topological feature maps uniquely representing the  
25      underlying signal's characteristics. Thus, complex input  
26      information is converted to simpler forms, i.e. topological

1 feature maps, has an important impact upon the overall training  
2 requirements connected with making the hybrid neural network  
3 operational. Specifically, as a result of the presence of the  
4 feature maps, the network's learning process is accelerated and  
5 the training time is reduced significantly.

6 Since the topological maps obtained from the two feature  
7 extraction networks 22 and 24 are a unique representation of each  
8 input pattern, the network provides a highly accurate pattern  
9 classification.

10 While the invention has been described in combination with  
11 specific embodiments thereof, it is evident that many  
12 alternatives, modifications and variations will be apparent to  
13 those skilled in the art in light of the foregoing description.  
14 Accordingly, it is intended to embrace all such alternatives,  
15 modifications, and variations.

16

1 Navy Case No. 78001

2

3 HYBRID NEURAL NETWORK FOR PATTERN RECOGNITION

4

5 ABSTRACT OF THE DISCLOSURE

6 A system for recognizing patterns comprises a first stage  
7 for extracting features from inputted patterns and for providing  
8 topological representations of the characteristics of the  
9 inputted patterns and a second stage for classifying and  
10 recognizing the inputted patterns. The first stage comprises two  
11 one-layer neural networks and the second stage comprises a  
12 feedforward two-layer neural network. A method for recognizing  
13 patterns is also described, which method broadly comprises the  
14 steps of providing first and second neural networks, each having  
15 an input layer formed by a plurality of input neurons and an  
16 output layer formed by a plurality of output neurons, supplying  
17 signals representative of a set of inputted patterns to the input  
18 layers of the first and second neural networks, training the  
19 first and second neural networks using a competitive learning  
20 algorithm, and generating topological representations of the  
21 input patterns using the first and second neural networks. The  
22 method further comprises providing a third neural network for  
23 classifying and recognizing the inputted patterns and training  
24 the third neural network with a back-propagation algorithm so  
25 that the third neural network recognizes at least one interested  
26 pattern.

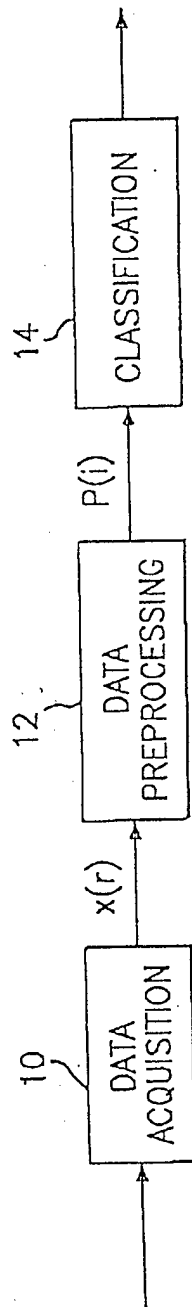


FIG. 1  
(PRIOR ART)

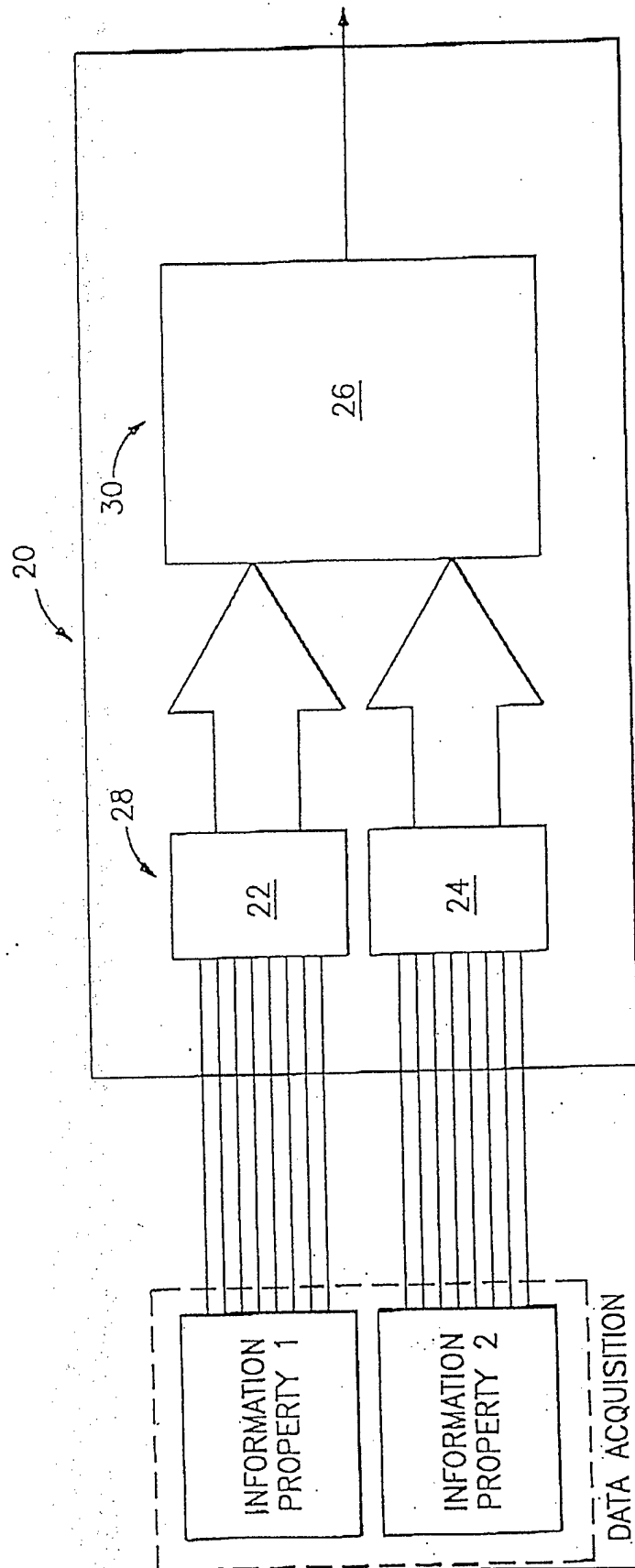


FIG. 2



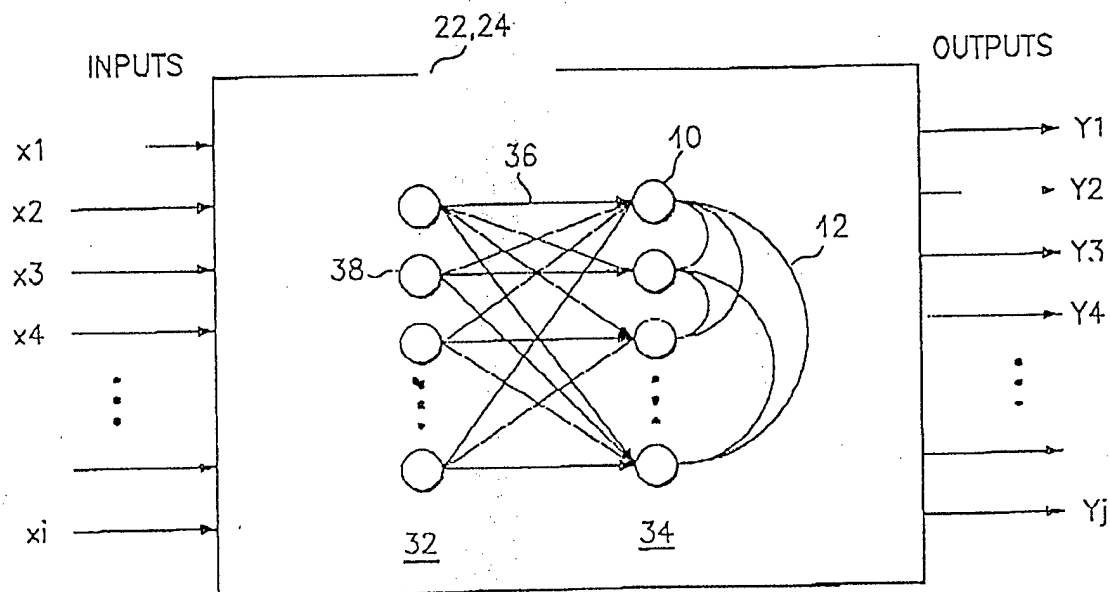


FIG. 3

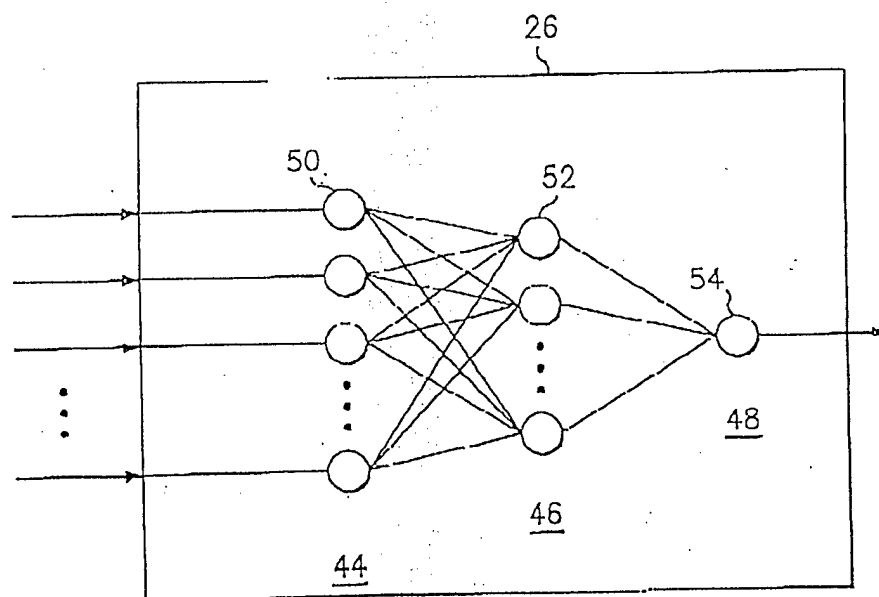


FIG. 4